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# The technology of automatic control of heat consumption in buildings

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**Abstract**

The paper is devoted to development and research of buildings' heat consumption management technology. Schematics of heat consumption management for CHP and low-grade as heat sources discussed. Analysis of management system capability during spring and autumn seasons conducted. The research was made with numerical approach. Adequacy of implemented models and methods was proved. Engineering and operational recommendations were made for management of buildings' heat consumption systems. Higher efficiency of buildings was proved while implementing developed technology regardless of heat sources. Management technology efficiency showed dependency on its schematics, heat-carrier temperature and temperature of low-grade heat source (for schematics with heat pump).

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*Keywords:*Buildings; Heat consumption; Automatic control; Investigation; Efficiency

## 1. Introduction

A greater part of heat energy generated by CHP and boiler houses in Russia is used for residence buildings heating [1, 2]. Besides, weather conditions in Russia in some regions require heating not only in winter time but also in other seasons. In the central part of Russia heating is required in the period from the middle of October to the middle of April. This period is longer for the regions with rigorous climate [3].

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As heat energy consumption for heating is high enough, it is vitally important to decrease heat consumption in buildings and other structures. One of the ways which allows to decrease heat consumption required for heating is the use of automated management and climate control technologies [4-7]. For the reasons of nature conservation great attention is paid at the systems that use low grade heat sources in their work (that is heat energy of soils, air, discharge and drain). As such systems do not burn fuel, they make possible to effectively use heat consumption energy while switching heat consumption alternating modes. Meanwhile, only limited number of research papers [7-10] try to examine combined work of heat consumption in buildings control systems and heat pumps (low grade heat sources). This article compares control systems of heat consumption in buildings using conventional heat sources and those using low grade heat sources.

**Nomenclature**

| | |
|---|---|
| $\rho_{in}$ | density of indoor air |
| $c_p$ | specific heat capacity of air at constant pressure |
| $V$ | airspace of the room |
| $t_{in}$ | indoor air temperature |
| $t_{out}$ | open air temperature |
| $\tau$ | time |
| $k_v$ | coefficient which takes account of the heat loss for warming input air |
| $k_h$ | heating units heat exchange coefficient |
| $F_h$ | heating units space |
| $t_1$, $t_2$ | heat-transfer medium temperature in the main pipe and in the return line consequently |
| $k$ | building envelopes coefficient of heat transfer |
| F | building envelopes space |
| $g$ | coefficient of heat-transfer medium mixture |
| $G_{inf}$ | indoor air output |
| $k_{fl}$ | coefficient which compensates for the heat loss through the floor |
| $Q_s$ | solar radiation heat input through windows |
| $v$ | coefficient of heat input decrease because of building envelopes thermal response |
| $\xi$ | coefficient of heating systems automated heat transfer efficiency |
| $\beta_h$ | coefficient which takes account of additional heat consumption by the heating system |
| $G_h$ ,$t_h$ | discharge and temperature of warm air which comes into the building |
| $t_{in1}$ | temperature of air which goes for further heating |
| $t'_{out}$ | open air temperature for the most cold five days chosen from 50-year observation |
| $t_{out1}$ | open air temperature in the beginning of heating season |
| $t_{in}(0)$ | indoor temperature at the initial time |
| $t_{in}(\tau)$, $t_{in}(\tau')$ | indoor temperature at the current time and at time $\tau'$ of temperature stabilization |

## 2. Technology of automatic control of heat consumption in buildings

It is important to note that automated management technologies efficiency depends on the electronic network of control equipment arrangement, heat consumption system structure, the source of heat (CHP, boiler house, low grade source), external factors (heat-transfer medium type and characteristics) and heating-performance of the building.

Figure 1 presents two main diagrams of control system of heat consumption in buildings arrangement: Diagram (a) showing a system with a conventional heat source; Diagram (b) showing the system with a low grade heat source.

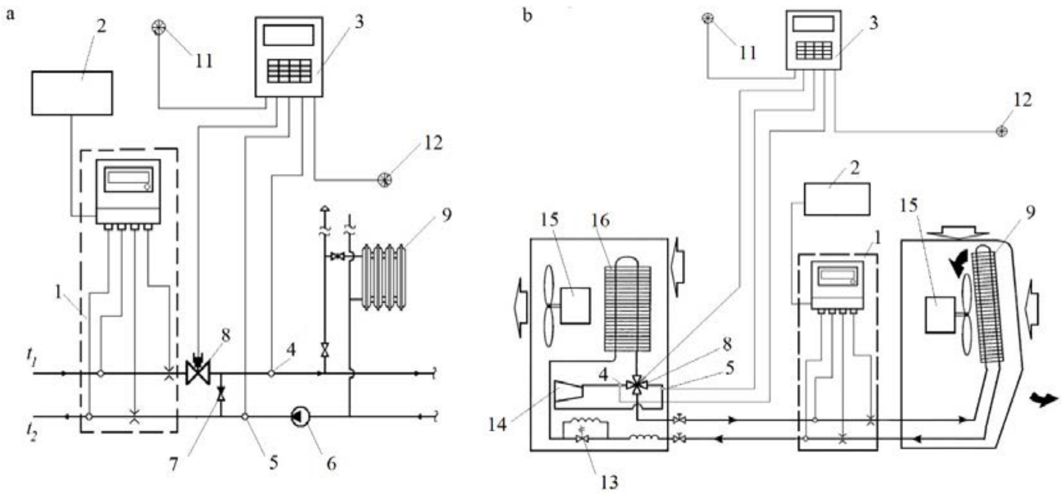


Fig.1 (a) a control system of heat consumption in buildings with a conventional heat source;
(b) a control system of heat consumption in buildings with a low grade heat source.

The control system of heat consumption in buildings shown on Figure 1 (a) uses CHP heating and works in the following way: The amount of heat coming from a conventional heat source (CHP or boiler house) is calculated by Heat meter 1 on entering the system. Here working conditions of the system can be either shown on a computer display or printed out with Information output system 2. This heat consumption system is controlled by Temperature monitoring system 3 while following a certain algorithm [11]. Heat-transfer medium (that is water) temperature in the main pipe (coming from the heat source) is recorded by Temperature sensor 4, and heat-transfer medium temperature in return line (coming to CHP) is recorded by Temperature sensor 5. Heat-transfer medium circulation in heating facilities is performed by Pump 6. After heat-transfer medium with $t_1$ temperature comes into the system from either CHP or boiler house it is mixed with heat-transfer medium which has come back with $t_2$ temperature. To prevent high temperature heat-transfer medium (with $t_2$, $p_1$ characteristics) from entering the return line Return valve 7 is used. Heat-transfer media mixture characteristics are controlled by Regulator 8. When leaving Regulator 8 heat-transfer medium goes into Heating units 9. Control characteristics are calculated in Temperature monitoring system 3 with account of data received from Temperature sensors 4 and 5, from Open air temperature sensor 11 and from Indoor air temperature sensor 12. The system also takes into account wind effect that usually leads to additional heat leakage. Solar radiation heat input is also registered. All that is done as provided by the algorithm in Temperature monitoring system 3.

The control system of heat consumption in buildings shown on Figure 1 (b) uses heat pump heating and works in the following way: Low temperature heat-transfer medium (Freon) circulates in the heat pump closed-loop. This heat-transfer medium (Freon) absorbs heat from a low grade source (that is environment: air, river, drain, etc), steams off and goes into Air pump 14. Air pump 14 compresses Freon; its temperature and pressure increasing. Before it comes into the building inner circuit, Freon temperature is measured by Temperature sensor 4. When Freon goes out of the inner circuit, its temperature is measured by Temperature sensor 5. After leaving the air pump this heat-transfer medium goes into the system inner circuit through Four-way valve 8 which is inside the building. While circulating within the inner circuit, the heat-transfer medium heats indoor air. Meanwhile, Compressor 15 makes indoor air circulate. At the same time the heat-transfer medium (Freon) cools off and condensates. After that the low temperature heat-transfer medium goes into the outer loop which is outside the building. In the outer loop this heat-transfer medium (Freon) is directed into the capillary pipe for pressure release. Then this low-pressure liquid Freon goes out of the capillary pipe through Control valve 13 and enters Heat-exchange unit 16 to consume heat from low grade heat source. Heat-carrying agent circulation through Heat-exchange unit 16 is performed by

Compressor 15. After going out of Heat-exchange unit 16 Freon gas is directed through Four-way valve 8 to Air pump 14 for pressure. Then this cycle process is repeated.

## 3. Research

The research of both heat consumption control systems of buildings supplied by conventional heat sources and by low grade heat sources was done by using numeric modeling verified by experimental data [7, 11].

The authors worked out a mathematical model for investigating heat consumption control systems of buildings and their operation. This mathematical model considers a building as an object with lumped parameters; building envelopes coefficient of heat transfer is considered to be permanent. This mathematical model consists of equations for calculating heat-transfer medium temperature in the central system (when heating is supplied by either CHP or boiler house), equations for calculating heat pump characteristics (when low grade heat source is involved), equations for calculating amplitude-frequency and phase frequency characteristics of automated heat control system and a dynamic equation of the system inertia members interaction. The latter is a dynamic equation of heated space. For a heat consumption control system for buildings with a conventional heat source (CHP or boiler house) this equation is as follows:

$$\begin{aligned} &\rho_{in} \cdot c_p V \frac{dt_{in}}{d\tau} = k_h \cdot F_h (1 - k_v - k_{fl}) \cdot \left[ \left( t_1 g + t_2 (1-g) \right) - t_{in} \right] - \\ &- k \cdot F \cdot (t_{in} - t_{out}) - c_p \cdot G_{\inf} \cdot (t_{in} - t_{out}) + Q_s \nu \zeta \beta_h \end{aligned} \quad (1)$$

For a heat consumption control system for buildings with a low grade heat source this dynamic equation is as follows:

$$\begin{aligned} &\rho_{in} \cdot c_p V \frac{dt_{in}}{d\tau} = c_p \cdot G_h \cdot (t_h - t_{in1}) \cdot (1 - k_v - k_{fl}) - \\ &- k \cdot F \cdot (t_{in} - t_{out}) - c_p \cdot G_{\inf} \cdot (t_{in} - t_{out}) + Q_s \nu \zeta \beta_h \end{aligned} \quad (2)$$

When modelling the system shown on Figure 1 (a) we used the following formula to calculate heat-transfer medium temperature in the main pipe (when coming from the heat source, CHP or boiler house) [7, 11, 12, 13]:

$$\begin{cases} t_1 = t_{in} + \Delta t \cdot \left( \dfrac{t_{in} - t_{out}}{t_{in} - t'_{out}} \right)^{0,8} + \left( \Delta t_t - 0{,}5 \cdot \Theta \right) \cdot \left( \dfrac{t_{in} - t_{out}}{t_{in} - t'_{out}} \right) \\ \Delta t = 0{,}5 \cdot \left( t_3 + t_2 \right) - t_{in} \\ \Theta = t_3 - t_2 \\ \Delta t_t = t_1 - t_2 \end{cases} \quad (3)$$

To calculate heat-transfer medium temperature in the return line (when the heat-transfer medium comes back to CHP or boiler house) we used the following equation [7, 11, 12, 13]:

$$t_2 = t_{in} + \Delta t \cdot \left( \frac{t_{in} - t_{out}}{t_{in} - t'_{out}} \right)^{0,8} - 0{,}5 \cdot \Theta' \cdot \left( \frac{t_{in} - t_{out}}{t_{in} - t'_{out}} \right) \quad (4)$$

The mathematical model also includes equations for computer-assisted management systems transient characteristics. For the system supplied by conventional heat sources (CHP, boiler house) shown on Figure 1 (a) transient time response is calculated by Equation 1 [7] with single step change in open air temperature [7]:

$$t_{out}(\tau) = \left(1 - exp^{-100\cdot\tau}\right)\cdot\left(t_{out} - t_{out1}\right) + t_{out1}. \tag{5}$$

Thus, time response in transient period for a heat consumption computer-assisted management control system in a building supplied by CHP was calculated as provided by the equation [7]:

$$T_{01} = \frac{\rho_{in}\cdot c_p V}{k_h F_h (1 - k_v - k_{fl}) + kF + c_p G_{\inf} + Q_s \nu\zeta\beta_h}. \tag{6}$$

For the heat consumption computer-assisted management control system supplied by low grade heat sources (heat pump) transient time response is calculated by Equation [7] :

$$T_{02} = \frac{\rho_{in}\cdot c_p \cdot V}{c_p \cdot G_h \cdot (1 - k_v - k_{fl}) + k\cdot F + c_p \cdot G_{\inf} + Q_s \cdot \nu\cdot\zeta\cdot\beta_h}. \tag{7}$$

Relative indoor air temperature under unit step input for the systems shown on Figure 1 (a and b) is calculated by the equation [7, 14]:

$$\tilde{t}_{in} = \frac{t_{in}(\tau) - t_{in}(0)}{t_{in}(\tau') - t_{in}(0)} \tag{8}$$

This mathematical model together with means and methods of numerical research has been verified by comparing experimental data of heat consumption computer-assisted management control system operation (shown on Figure 1 (a)) with numerical results. For that purpose, the mathematical model takes account of some basic data. It is meteorological observation data approximated while using trigonometric functions with the involvement of mathematical apparatus technique of random number generator. Results of the mathematical model verification and the numerical results of heat consumption computer-assisted management control system operation are shown on Figure 2. The data shown on Figure 2 prove that calculation results and experimental research results are almost the same. The difference is well withing the experiment operation almargin.

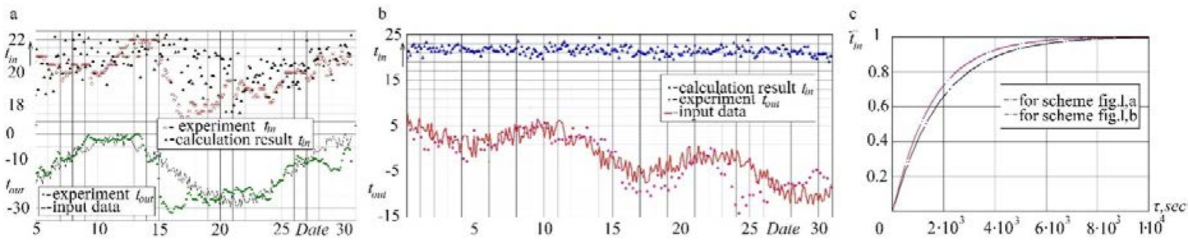


Fig. 2. (a) Mathematical model verification. Experimental research for a typical winter month;
(b) Numerical results of autumn weather conditions for Fig.1.,a; (c) Indoor air relative temperature under unit step input.

Temperature change ratio error is $\delta_{tin}$=±2%, $\delta_{tout}$=±1.7%, for heat-transfer medium temperature is $\delta_t$=±0.9%, for coefficient of heat transfer is $\delta_k$=±2.1%, for mixture coefficient is $\delta_g$=±1.6% for confidence coefficient is 0.95. The introduced models and methods can be also used for heat consumption computer-assisted management control system numerical study. Figure 2 also shows numeric modeling results for computer-assisted management control system (Fig. 1, a) in the period of heating system light loading which is typical for autumn. Weather conditions of October 2014 are used in this calculations. Calculation results show that the system is adequate for changes in open air temperature. Still indoor air temperature is 0.5-1.5°C higher than the optimal temperature: $t_{in}$ (opt)=22 °C. Figure

2 (c) compares two systems (heat consumption control system with conventional heat sources and with low grade heat sources). The calculations are given with account of unit step input. Calculations shown on Figure 2 (c) prove that the system with low grade heat sources (Fig. 1, b) is 20% more effective in its unit step input reaction than the system with heat consumption from conventional heat sources (Fig. 1, a).

## 4. Conclusion

It is important to note the use of automated management heat consumption technologies allows to increase heat consumption efficiency for 30-40% depending on a heating systems schematics. Thus, computer-assisted management control systems implementation reduces costs of city infrastructure maintenance in general. The use of unconventional heat sources can also considerably improve the environment [15-20].

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